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Technical Report 67-3

Aircraft Detection, Range Estimation, and Auditory Tracking Tests in a Desert Environment

by

Edward W. Frederickson, Joseph F. Follettie, and Robert D. Baldwin

HumRRO Division No. 5 (Air Defense)

AD ________

March 1967

Prepared for:

Office, Chief of Research and Development Department of the Army

Contract DA 44-188-ARO-2

HumRRO

The George Washington University
HUMAN RESOURCES RESEARCH OFFICE
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DEPARTMENT OF THE ARMY
OFFICE OF THE CHIEF OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C. 20310

March 29, 1967

CRDHF

SUBJECT: Aircraft Detection, Range Estimation, and Auditory Tracking Tests in a Desert Environment

TO:

1. This report concerns tests made to determine man's capabilities in aircraft detection, range estimation and auditory tracking of low-flying jet aircraft under optimum field conditions.

2. Observers were located at various distances from the flight path and their ability to detect aircraft visually and auditorily and to estimate the distance to the aircraft was tested. The amount of early warning given the observers was varied; observers used binoculars or unaided vision in detecting aircraft and recognizing structural features.

3. Results indicated that if visibility is good, the terrain unobstructed, and observers have reasonably accurate early warning, they can visually detect aircraft more than 10,000 meters away, on the average. Using binoculars did not appreciably aid detection and in some cases delayed it. In the auditory tracking tests, observers consistently placed the aircraft ahead of its actual position.

4. The findings of this report should be of interest to those responsible for personnel requirements and training for visually sighted air defense weapons.

FOR THE CHIEF OF RESEARCH AND DEVELOPMENT:

1 Incl
as

ROBERT B. BENNETT
Colonel, GS
Acting Chief, Human Factors and
Operations Research Division

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HumRRO Division No. 5 (Air Defense)
Fort Bliss, Texas

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HUMAN RESOURCES RESEARCH OFFICE
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Technical Report 67-3
Exploratory Study 44

The Human Resources Research Office is a nongovernmental agency of The George Washington University, operating under contract with the Department of the Army (DA 44-188-ARO-2). HumRRO's mission is to conduct research in the fields of training, motivation, and leadership.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

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FOREWORD

In December 1964 the U.S. Army Combat Developments Command, Air Defense Agency, recommended that the Human Resources Research Office initiate research in "the areas of visual surveillance, detection, identification, and range estimation in support of military studies of the effectiveness, doctrine, manpower requirements and training for visually sighted air defense weapons." In support of this research requirement and related ones expressed by the U.S. Continental Army Command, HumRRO Division No. 5 (Air Defense) initiated an intensive program of studies on these problems in late FY 1965.

This report describes tests of several of the visual and auditory skills required for operation of forward area air defense weapons. The tests were initiated as part of HumRRO Exploratory Study 44, Training Methods for Forward Area Air Defense Weapons. This report supersedes an interim report made in October 1965 to Army agencies directly concerned with doctrine, training, and materiel requirements associated with forward area weapons. The present report and Technical Report 66-19, The Performance of Ground Observers in Detecting, Recognizing, and Estimating Range to Low-Altitude Aircraft, December 1966, complete the reporting of work under ES-44. These studies were continued during FY 1966 as HumRRO Work Unit SKYFIRE.

The tests described in this report were accomplished in June and July 1965 in the vicinity of Tonopah, Nevada, using aircraft flights assigned in support of the Joint Chiefs of Staff, Joint Task Force Two, Low Altitude Penetration Test 1.0. The assistance and cooperation provided by the staff of Joint Task Force Two is greatly appreciated.

The tests were conducted by HumRRO Division No. 5 (Air Defense). Military support was provided by the U.S. Army Air Defense Human Research Unit, under the command of LTC Leo M. Blanchett, Jr., Unit Chief. The HumRRO Test Control group consisted of Mr. Edward W. Frederickson, Dr. Joseph F. Follettie, Dr. Paul G. Whitmore, and Dr. Robert D. Baldwin. The observers were LTC Walter E. Burrell (Ret.), Mr. Robert J. Foskett, Dr. Frank B. Nelson, SFC Edward P. Bedy, SP 4 James L. Claflin, SP 4 Judson D. Human, SP 4 Stanley A. Sliko, and SP 4 Glenn W. Wortham.

HumRRO research is conducted under Army Contract DA 44-188-ARO-2, and under Army Project No. 2J024701A712 01, Training, Motivation, Leadership Research.

Meredith P. Crawford
Director
Human Resources Research Office

SUMMARY AND CONCLUSIONS

Military Problem

Use of visually sighted air defense weapons requires various perceptual skills of the human operator. Requirements include (a) the visual detection and identification of aircraft, (b) the estimation of range, altitude, and speed, (c) visual and manual tracking of target aircraft, (d) the determination of when the target is within the performance envelope of the weapon system, and (e) the application of an effective technique of fire. The Army needs information concerning human capabilities to perform these functions in order to determine job procedures and the type of training needed for operation of air defense weapons.

Research Objectives

There were four objectives in the field studies reported here:

(1) To obtain data concerning the effect on the visual detection range for jet aircraft of (a) varying the location of observers relative to the flight path, (b) using binoculars of 6x30 and 7x50 power, and (c) varying the amount of temporal early warning given the observers.

(2) To obtain preliminary information concerning man's ability to estimate the distance to aerial targets.

(3) To conduct an exploratory test of auditory detection and tracking skills.

(4) To determine the ranges at which an aircraft's structural components are recognized.

These studies were a continuation of Human Resources Research Office studies at Fort Bliss, Texas, reported in HumRRO Technical Report 66-19, *The Performance of Ground Observers in Detecting, Recognizing, and Estimating Range to Low-Altitude Aircraft* (1).

Research Method

The tests were conducted in a desert environment near Tonopah, Nevada. The jet aircraft, used as targets, were being flown in support of another test being conducted by Joint Task Force Two of the Joint Chiefs of Staff. The aircraft flew at very low altitudes and at tactical speeds over a fixed flight path clearly marked on the ground. The aircraft flew north to south and *vice versa*. Observers were stationed at four observation posts (OPs) located 200, 1,400, 2,600, and 3,300 meters west of the flight path. The observers' view to the south was unobstructed for approximately 15,000 meters, but to the north there was an intervening land mass that provided varying degrees of masking, depending upon the OP's offset and the aircraft's altitude.

Eight observers detected jet aircraft under various test conditions requiring the use of either unaided or aided vision or auditory cues, and when either one or five minutes of early warning was given. For part of the flights the observers, following initial detection, named the structural details of the aircraft as each came into view. In other tests the observers had to estimate the distance to the target.

Results

Detection Tests

In the detection tests, comparisons were made between the following conditions:

(1) Visual and auditory detection.

(2) Unaided and binocular-aided vision.

(3) 6x30 and 7x50 binoculars.
(4) One and five minutes of early warning.
(5) Amount of offset distance from the flight path.
(6) Varying distances to the terrain mask.

Visual vs. Auditory Detection. When averaged over all OPs, target aircraft flying from near terrain masking were detected visually about 500 meters before they were heard. The difference between the visual and auditory detection ranges decreased as the amount of terrain masking increased.

Unaided vs. Aided Detections. The difference between the unaided and binocular-aided detection ranges was not the same for the near and the far terrain masking conditions. Under conditions of *far* terrain masking, the mean unaided and 6x30 aided visual detection ranges were not reliably different; the mean detection range averaged over both systems was 12,000 meters. However, under conditions of *near* terrain masking (4,000 to 6,000 meters), detection occurred earlier when 6x30 glasses were *not* used.

6x30 vs. 7x50 Binoculars. There was no reliable difference between the mean detection ranges for the 6x30 and 7x50 binoculars.

Amount of Early Warning. The comparison between one and five minutes of temporal early warning did not produce a reliable difference in detection ranges under either far or near terrain masking conditions.

Observer Offset. There were reliable (i.e., statistically significant) differences among the detection ranges for the four observation posts. As the amount of offset (and OP elevation) increased, the mean detection range increased from about 9,800 to 14,500 meters.

Range Estimation

The range estimation tests required the observers to estimate distances varying between 1,000 and 5,000 meters. The average algebraic errors of estimation decreased as the offset distance increased. At the 200-meter OP the observers underestimated the ranges by approximately 475 meters, whereas at the 3,300-meter OP the average error was an overestimation of about 50 meters. The variability among observers also decreased as the offset distance increased.

Structure Recognition

The distance at which various aircraft structural components were detected varied with the class of aircraft observed. However, within each class (i.e., bombers or fighters) there tended to be a consistent rank order in which the components were seen. The average response delay between the initial detection response and the first structure recognition response (2.7 seconds for fighters when binoculars were used) was longer for unaided vision than for binocular-aided vision.

Auditory Tracking

The exploratory auditory tracking tests revealed that untrained observers consistently tracked the target ahead of its position. The average human tracking error became more consistent as the aircraft progressed from inbound to outbound. The constancy of the average human error indicates the dependence of the total tracking error on acoustic lag.

Conclusions

(1) The visual detection tests support the results obtained in earlier HumRRO tests at Fort Bliss. If observers (a) are not subiect to near terrain masking, (b) have good visibility, and (c) have reasonably accurate early warning information, they can detect jet aircraft on the average at distances in excess of 10,000 meters.

(2) The results of earlier HumRRO tests concerning the use of field glasses were also supported. Under the environmental conditions described above, unaided detections were as effective as detections involving the use of field glasses.

(3) In contrast, the terrain masking test results suggest that field glasses should not be used for detection when relatively near terrain masking occurs. Additional tests would be necessary to determine whether recognition is aided under these conditions if glasses are *not* used for detection but *are* used for recognition.

(4) The auditory detection and tracking studies raise a possibility that the capabilities of some fair weather forward area weapons can be extended to poor visibility conditions. Additional studies of auditory tracking would be necessary to determine whether observers can be trained to compensate for tracking errors due to sound propagation time delays.

(5) The range estimation tests produced inconclusive results because of certain characteristics of the test environment used. The results indicated that observers who were offset from the flight path made more accurate estimates than observers who viewed the aircraft from a head-on aspect. However, these results were obtained under conditions where the crossover distance of the flight path was known to the observers, a condition not likely to occur in combat.

(6) In the recognition tests, when far terrain masking existed the use of field glasses increased the range at which various structures were recognized. However, when near terrain masking existed the response delay between initial detection and the first recognition response was not reduced by use of field glasses. The test results also indicated a consistency in the order in which the structural components of aircraft were seen. It would appear that this consistency could be used as an aid for range estimation.

CONTENTS

Aircraft Detection, Range Estimation, and Auditory Tracking Tests in a Desert Environment

Chapter 1

THE RESEARCH APPROACH

MILITARY PROBLEM

The increased emphasis on low-altitude air assault tactics by both U.S. and foreign armies creates a reciprocal need to provide increased air defense capabilities for deployed U.S. ground forces.

The weapons that could be available in the near future for low-altitude air defense are (a) small arms organic to the infantry company, (b) the larger caliber automatic weapons, (c) the man-transportable Redeye missile system, and (d) the Chaparral air defense weapon.

In contrast to the radar-controlled air defense systems that generally are deployed to the rear of the field army area, the weapons being considered by the Army for forward area air defense operations are man-ascendant rather than machine-ascendant systems. The man-ascendant weapons depend upon basic human skills to (a) detect and recognize the aircraft, (b) estimate the distance, altitude, and speed, (c) track the target, (d) determine when the target is within the air defense weapon's capability envelope, and (e) engage the target. At the present time, these man-ascendant weapons are considered to be fair weather systems only. That is, they have little or no capability under conditions of poor visibility unless aided by supplemental detecting and tracking systems.

RESEARCH PROBLEM

The tests reported here had the following objectives:

(1) To obtain data concerning the effects on visual detection of (a) the amount of lateral offset of the observers from the flight path of the aircraft, (b) the type of visual aids employed and their optical power, and (c) the amount of early warning given the observers.

(2) To obtain information concerning man's ability to estimate the range of low-flying aircraft.

(3) To conduct exploratory tests of man's skill in using auditory cues for detection and tracking. These auditory skills, when used in conjunction with infrared passive viewing devices, might extend system capabilities to limited visibility conditions.

(4) To determine the distances at which the structural components of aircraft are detected. This information is not only relevant to the broader study of aircraft recognition training, but also is related to studies of methods of teaching range estimation.

These tests were a continuation of earlier HumRRO studies on detecting, recognizing, and estimating range to low-flying aircraft, conducted at Fort Bliss, Texas (1).

Flight Path and Location of Observation Posts

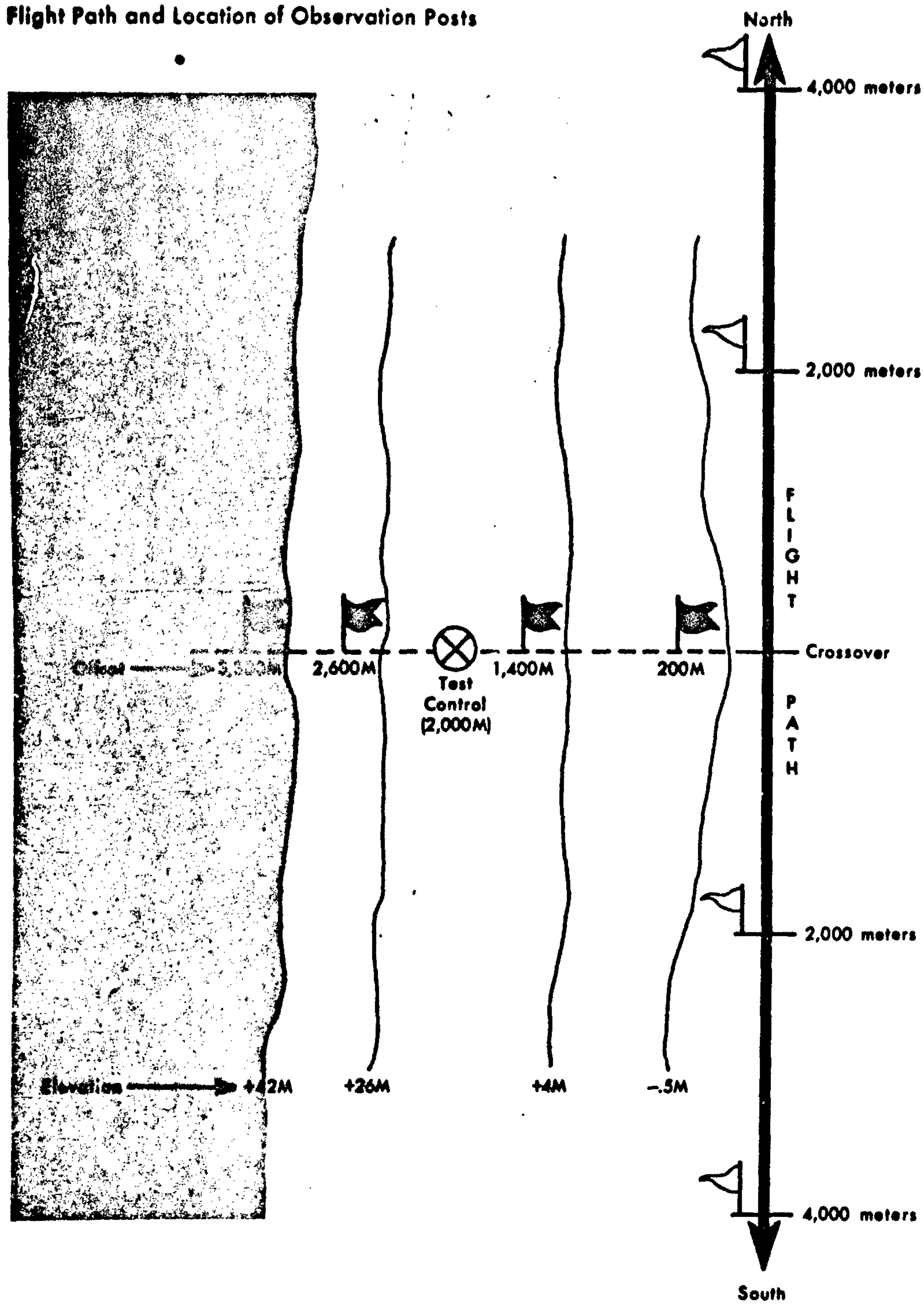


Figure 1

METHOD

Test Limitations

The human factors tests reported here used a test environment created for an entirely different purpose by Joint Task Force Two (JTF-2) of the Joint Chiefs of Staff, Department of Defense. The human factors tests of ground observers were attached in a subordinate position to the JTF-2 test on a not-to-interfere basis. As a result, these tests were limited in several respects.

First of all, although several jet aircraft were flown in support of the JTF-2 tests, usually only one type of aircraft flew on any one day. This characteristic eliminated the possibility of conducting the usual type of aircraft recognition tests. During the period of time encompassed by the ground observer tests (1 June through 6 July, 1965), the following aircraft were flown: the F-4C, F-105, and A-6 fighters and the B-52 and B-58 bombers.

The second limitation concerned the courses flown by the test aircraft. The aircraft flew over a constant flight path clearly marked on the ground by flame orange, 50-gallon barrels. The aircraft flew either north to south or vice versa according to a prearranged schedule. The flame orange barrels were visible to the ground observers. As a result, the observers acquired knowledge of the expected sector of appearance of the aircraft.

A third limitation concerned the time of day when the flights occurred. On most days, the trials were scheduled from sunrise to late morning. Since only a single set of four observation posts were used, the positions of the sun, relative to the aircraft and the observers, were not representative of the complete array of all possible target-observer-sun angles.

A fourth limitation concerned the availability of range measuring instrumentation. As will be described later, a dead-reckoning procedure was used to determine aircraft distance at any given instant. This procedure involved a modification of a "police trap" method, in which the time required to traverse a known distance was used to compute the aircraft's position at earlier time intervals. This procedure assumed that the aircraft's speed over flat terrain would be fairly constant.

A fifth limitation concerned the nonavailability from JTF-2 of unclassified information concerning the approximate altitude range of the aircraft while in the vicinity of the HumRRO test area. Informal opinion among the observers was that the altitude range for the several aircraft varied between 30 and 200 feet during the many trials flown.

Test Site and Visibility

The flight path was over a wide, flat desert valley between two lines of barren mountains that rose about 500 feet to the west and 1,500 feet to the east. The test site was located adjacent to the flight path on relatively flat terrain. The observers were located at four observation posts (OPs) at distances of 200, 1,400, 2,600, and 3,300 meters perpendicular to and west of the flight path. Figure 1 shows a plan view of the flight path and the location of the OPs with their approximate elevations. Details of the site instrumentation are contained in Appendix A.

View to the East. (See Figure 2) Looking east along the line of OPs, the terrain elevation decreased moderately for approximately one mile and somewhat more gradually thereafter. Since flights were from sunrise to late morning, observers were located to the west of the flight path to minimize glint from the approaching aircraft, presenting observers with a difficult detection and structure-recognition problem. Following the time at which the aircraft unmasked above the horizon, all aircraft had a mountain background.

Terrain View Looking East From Test Control

Figure 2

<u>View to the South</u>. (See Figure 3) The view of the flights coming from the south was uninterrupted to the distant horizon, approximately 15 miles away. As one moved from the near OP (200 meters from the flight path) to the most distant OP (3,300 meters), the near terrain east of the flight path increasingly became the background for the flight path of the aircraft.

<u>View to the North</u>. (See Figure 4) The view of the flights coming from the north was almost as good as that for those from the south, when the observer was sited at 200 and 1,400 meters. At the time of unmask, the aircraft had a sky background when viewed from the 200-meter OP. For the other OPs, the aircraft had a terrain (distant mountain) background at the time of unmask. In addition, a ridge intervened between the aircraft on a north to south flight and the 2,600-meter and 3,300-meter OPs. As a result, the observers at these positions were not able to see the aircraft until it was much nearer to cross-over (the intersection of the flight path and the observers' line of positions) than was the case at the near OPs. The obscuration was particularly severe when the aircraft was very low.

<u>Climatic Conditions</u>. In general, climate and atmospheric conditions were very good during the test days. Conditions varied somewhat, but visibility was never less than 40-50 miles. On four of the 20 test days there were varying amounts of cloud cover. Temperature varied from some early morning lows of 35° to late morning highs of 80°-85°. The average temperatures were about 50° for early morning and 75° for late morning. Winds varied from calm to breezes of about 12 to 15 miles per hour. The humidity varied between 10% and 30% most of the time.

Sample brightness measurements for early and late morning of an average day appear in Table 1.

Terrain View Looking South From Test Control

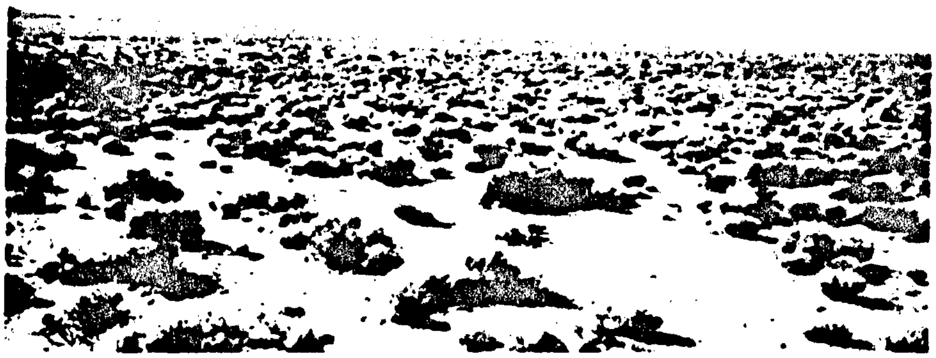


Figure 3

Terrain View Looking North From Test Control

Figure 4

The aircraft presented a negative contrast ratio (the aircraft was darker than the background) when seen against the sky and a positive contrast ratio when viewed against the terrain background.

Table 1

Background Brightness Measurements for Average Day

(Footlamberts)

Direction	Time	
	0710	1030
Sky		
North Horizon	1,900	3,000
South Horizon	1,400	3,400
Terrain		
Crossover Point (intersection of flight path and line of observer positions)	850	950

Measuring Aircraft Range

The dependent variable for all tests was the aircraft-to-observer distance at the time of detection, either visually or aurally, and/or the recognition of structural components.

Aircraft distance was measured by a dead-reckoning procedure involving manual timing of the aircraft as it traversed a known distance. Each aircraft was manually timed by HumRRO Test Control as it traversed a 4,000-meter known distance defined by boundary markers adjacent to the flight path. This time-of-flight measurement was converted to speed in meters per second.

At the time each observer detected the aircraft, he depressed a button that deflected a pen on a multi-channel, constant-speed event recorder located at HumRRO Test Control. When the aircraft subsequently passed the crossover point opposite the observers' line of positions, HumRRO Test Control activated a crossover pen.

The amount of recording paper intervening between the observer's detection mark and the crossover mark was converted to time.

Knowing the aircraft's speed in meters per second and the observer's location, his time of detection was converted to aircraft slant range at detection.

This method assumes that the aircraft's speed was constant over the flight path and that the manual timing of the aircraft was not subject to bias. To compensate for these assumptions, all distance measurements were rounded to the nearest 100 meters.

Observers

The same eight observers were used in all the tests. They consisted of five military personnel assigned to the U.S. Army Air Defense Human Research Unit and three civilian members of HumRRO Division No. 5. All of them were free of gross visual anomalies and had 20/20 vision, corrected if necessary. Seven of the observers had participated as test control staff during previous detection and recognition tests conducted at White Sands Missile Range. Although they had not served as observers during the earlier tests, they had accumulated a considerable amount of "airplane-watching" experience prior to the Tonopah tests.

Chapter 2

AIRCRAFT DETECTION TESTS

Tests were conducted to compare the average initial detection ranges for the following combinations of variables: (a) eye vs. ear, (b) eye vs. 6x30 binoculars, (c) 6x30 vs. 7x50 binoculars, (d) one minute vs. five minutes early warning, and (e) degree of terrain masking. All tests involved observations from the four offset observation posts.

PROCEDURE

Because of the limited number of aircraft sorties per day, only one test could be made on any one day. This necessitated the use of three different types of aircraft for the several comparisons of visual aids. In addition, the B-52 flights used in comparing visual and auditory detection were subject to the near terrain masking characteristic of the north-to-south flights. This was not the situation for the other tests, which used fighter aircraft flying from distant terrain masking.

Two observers were located at each of the four OPs and were rotated among the posts each day to offset any biases in the test data due to individual differences. The observers functioned independently of each other at each OP. One-minute early warning was given for all aircraft sorties except in the early warning tests. The latter used either one or five minutes of early warning.

On the test days used in this experiment, temperatures varied between 60° and 75°. Measurements of sound pressure level taken when there was little or no wind were too low to read (below 34 db.). A breeze of seven to eight mph increased the ambient noise level to about 45 db.

RESULTS

Visual vs. Auditory (Eye vs. Ear)

The mean and standard deviation of the distances of visual and auditory detections at each observation post are shown in Table 2. These observations were made of B-52 aircraft flying from near terrain masking.

Differences among this set of observations were examined by analysis of variance techniques with the following results:

(1) When averaged over all OPs, the visual detections were significantly earlier than auditory detections ($p < .05$).

(2) There was a significant ($p < .05$) interaction between the detection modality used and the observers' location. Observers located at the more lateral OPs tended to hear the aircraft either at the same time or before they saw it. In contrast, the observers at the OPs nearer the flight path tended to see the aircraft before they heard it.

The relationship between target range and the probability of detection for the visual and auditory observations of flights from the near terrain mask

Table 2

Mean Visual and Auditory Detection Ranges*

(Meters)

Detection Mode	Offset 200-Meter	1,400-Meter	2,600-Meter	3,300-Meter	All OPs
Visual					
Mean	6,050	5,200	5,400	4,850	4,850
Standard Deviation	2,050	1,240	750	940	1,600
Auditory					
Mean	4,300	4,000	4,400	4,550	4,300
Standard Deviation	2,180	1,920	1,750	1,700	1,870

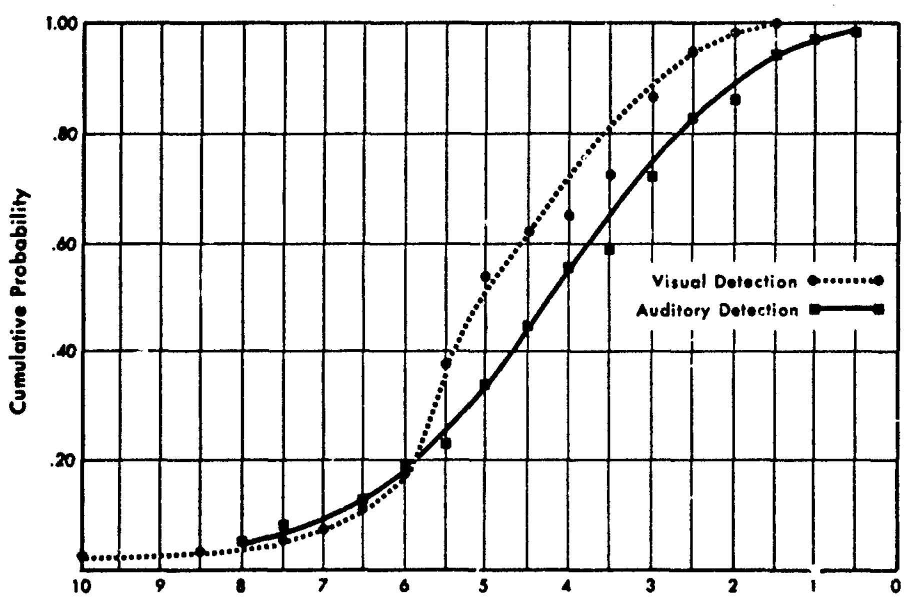
*The aircraft were flown from the near terrain mask.

is shown in Figure 5. The relationships between range and detections for each OP are shown for the visual and auditory observations in Figures 6 and 7 respectively.

Unaided Eye vs. 6x30 Binoculars

Observations were made of F-4C aircraft on the course subject to distant terrain masking. The mean detections at all OPs were 11,900 meters for the eye and 12,200 meters with the 6x30 glasses. The standard deviations were 3,360 and 2,800, respectively. The difference between these averages was not statistically significant.

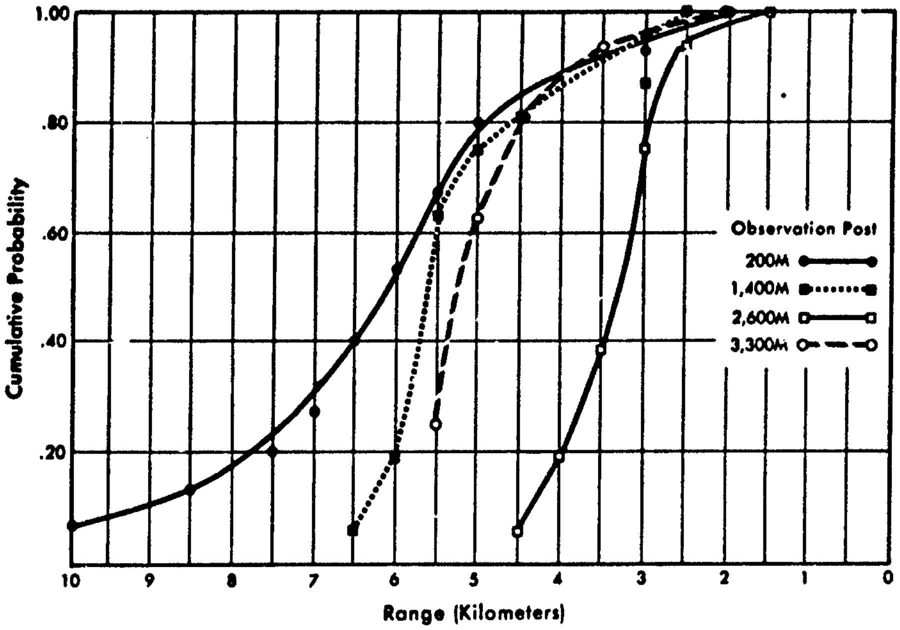
Auditory vs. Visual Detections for All Offsets (B-52, Near Masking)



Note: Where no point is plotted, observations had not yielded additional detections.

Figure 5

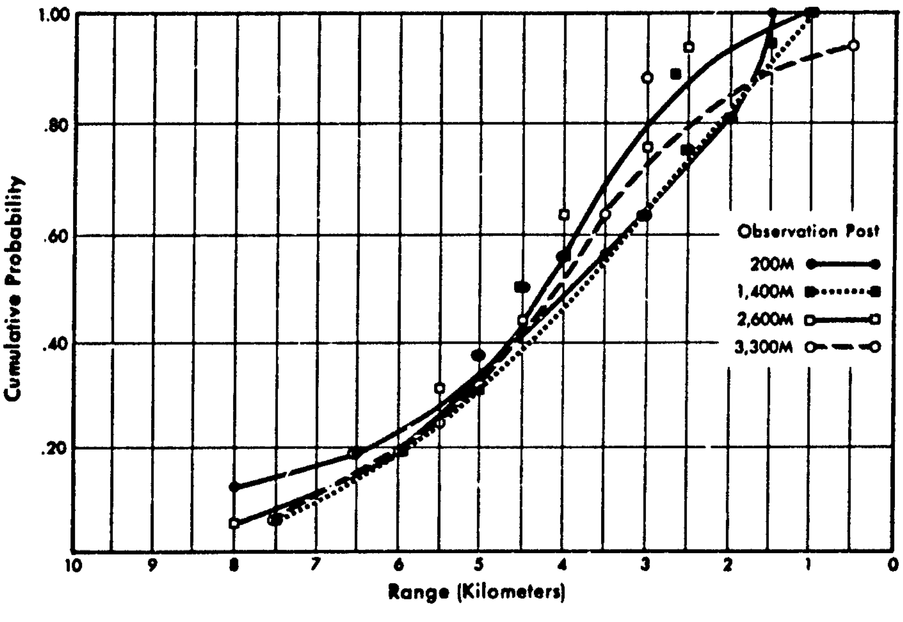
Visual Detections at Each Offset (B-52, Near Masking)



Note: Where no point is plotted, observations had not yielded additional detections.

Figure 6

Auditory Detections at Each Offset (B-52, Near Masking)

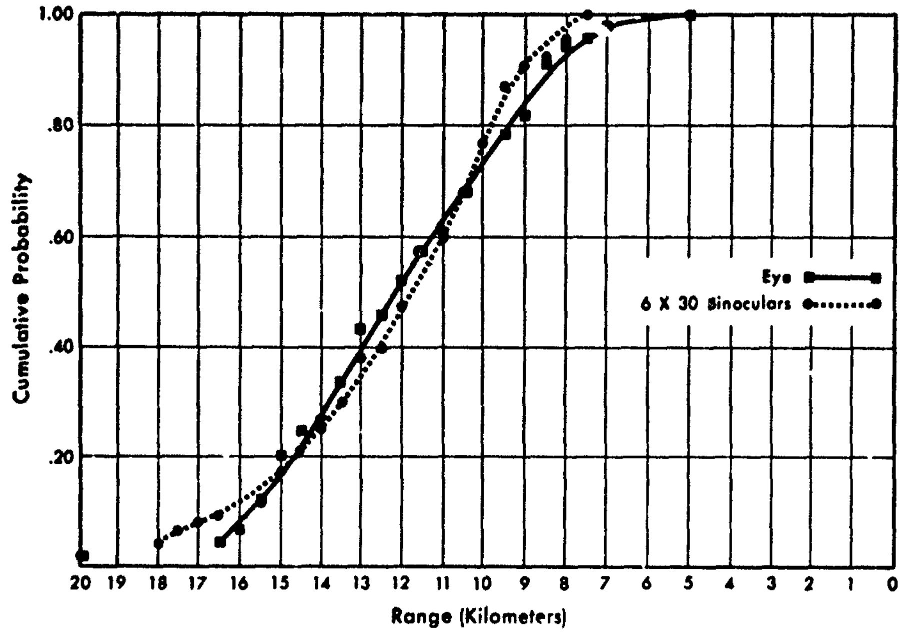


Note: Where no point is plotted, observations had not yielded additional detections.

Figure 7

The relationship between aircraft range and probability of detection for the unaided and 6x30 observations is shown in Figure 8.

Eye vs. Binocular Detections for All Offsets, (F-4C, Far Masking)



Note: Where no point is plotted, observations had not yielded additional detections.

Figure 8

6x30 vs. 7x50 Binoculars

This test again used the F-4C aircraft on the course involving distant terrain masking. The mean detection averages over all ranges were 12,700 meters and 12,850 meters for the 6x30 and 7x50 glasses, respectively. The corresponding standard deviations were 2,860 and 2,790. The difference between the average ranges at detection was not statistically significant. The relationship between aircraft distance and probability of detection was very similar to that reported for the eye vs. 6x30 comparisons.

One-Minute vs. Five-Minute Early Warning

This test used the F-105 aircraft, which flew courses involving both near and distant terrain masking. Under distant masking conditions the mean detection ranges averaged over all OPs were 12,150 meters for the one-minute condition and 12,750 meters for the five-minute condition. The corresponding standard deviations were 3,840 and 3,200 meters, respectively. The difference between the average detection ranges was not statistically significant. Under near masking conditions the detection ranges were 4,600 and 5,000 meters for the one-minute and five-minute warning. This difference was not statistically significant.

Lateral Distance From the Flight Line

The tests concerning the effect on detection of the observers' offset from the flight path used the F-4C aircraft flying the courses involving distant terrain masking. The mean detection ranges and standard deviations for each observation post are shown in Table 3.

Table 3

Mean Detection Range at Each Offset*

(Meters)

Statistic	Offset			
	200-Meter	1,400-Meter	2,600-Meter	3,300-Meter
Mean	9,820	11,300	14,600	14,260
Standard Deviation	595	900	740	1,375

*The aircraft were flown from the far terrain mask.

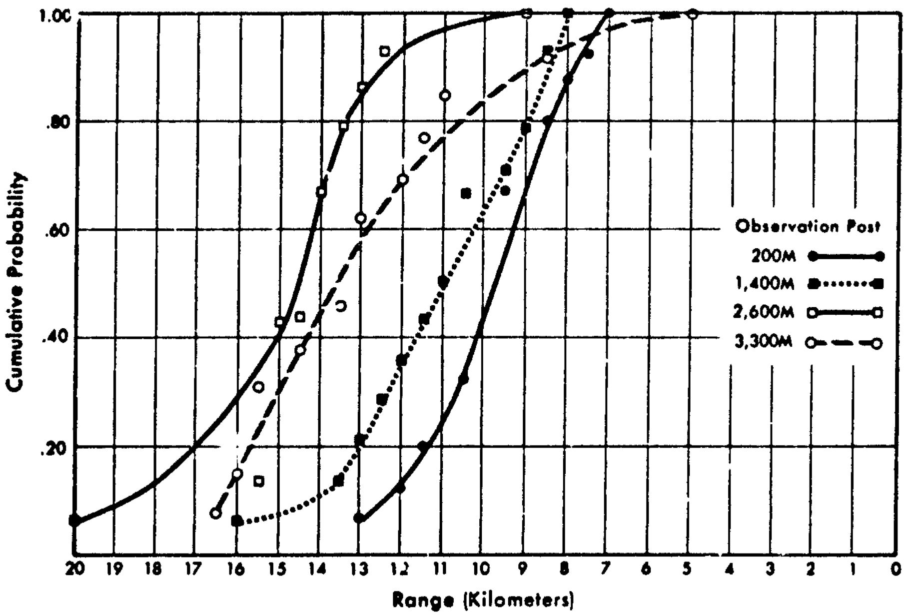
Differences among mean detection ranges at the several OPs were examined by analysis of variance techniques with the following results:

(1) OPs 1 and 2 were reliably different from each other and each was different from OP 3 and OP 4 ($p < .05$).

(2) OPs 3 and 4 were not different from each other.

The relationships between target range at detection and the probability of detection for each OP are shown in Figure 9.

Cumulative Probability of Detection at Each Offset (F-4C, Far Masking)



Note: Where no point is plotted, observations had not yielded additional detections.

Figure 9

Terrain Masking

In the Tonopah test situation, the flights from the north were subject to differential amounts of near terrain masking, depending upon the offset of the OP. Obviously, the visual detection of low flying aircraft is limited by the presence of terrain features that intervene between the observer and the aircraft. When near masking exists, the effectiveness of using binoculars for detection is questionable because (a) the aircraft would be super-threshold for unaided detection at the time of unmask, and (b) binoculars reduce the visual field during surveillance. Tests were conducted to evaluate the extent to which terrain masking affected the detection ranges obtained when binoculars were used.

On several days all aircraft flights were from the north—the near mask direction. On these days a detection study was conducted in which one-half of the observations used 6x30 binoculars and one-half used unaided vision.

The degree of masking was functionally evaluated for each OP by computing the ratio between the detection range to the north (near masking) and the detection range to the south (far masking). This ratio was then multiplied by 100 to yield a Percent Masking Index. These percentages were 38%, 55%, 77%, and 68% for the 200, 1,400, 2,600, and 3,300 meter OPs, respectively.

The mean and standard deviation of the detection ranges for the unaided and aided observations are presented in Table 4. The results are shown with reference to the increasing order of the Masking Index.

Table 4

Mean Detection Ranges by Eye and Binoculars for Aircraft Flown From Near Mask

(Meters)

Viewing Method	Offset Masking Index*				All OPs
	38% (200-Meter)	55% (1,400-Meter)	68% (2,600-Meter)	77% (3,300-Meter)	
Eye					
Mean	5,850	4,900	4,700	3,000	4,750
Standard Deviation	780	585	285	285	1,110
6 × 30 Binoculars					
Mean	6,000	4,650	4,200	3,000	4,600
Standard Deviation	620	800	420	280	1,230

*Masking Index = $\frac{\text{Detection Range, Near Masking}}{\text{Detection Range, Far Masking}} \times 100$

Although the results suggest that unaided detections occurred earlier for the unaided observations, statistical analysis revealed no significant differences between the aided and unaided detections.

Detection responses for near masked flights also were involved in the structure recognition tests to be discussed in Chapter 4. During the structure recognition tests one-half of the flights were from the near masked direction and observers were stationed at the 200-meter and 1,400-meter OPs. The mean detection ranges for the aided and unaided observations of the recognition tests are shown in Table 5.

These data again revealed a tendency for the unaided detections to occur before the aided observations. A statistical analysis of all detection ranges for

Table 5

Mean Detection Ranges by Eye and Binoculars for Aircraft Flown From Near Mask During Structure Recognition Tests

(Meters)

Viewing Method	Aircraft	Offset	
		200-Meter	1,400-Meter
Eye	F-4C	6,250	5,100
	A-6	6,700	5,050
6 x 30	F-4C	6,350	4,700
Binoculars	A-6	6,300	4,800

the near masked flights revealed that, of the 24 observations made by individual observers, only seven yielded earlier detections when binoculars were used. This was significantly different from the results that would have been expected had there been no difference between viewing methods ($p < .05$).

DISCUSSION

Auditory Detection

Although the study concerning auditory detection of aircraft was conducted using the B-52 aircraft, which has eight jet engines, there is reason to believe that these data can be extended to smaller jet aircraft with fewer engines flying at speeds similar to those employed for this test. Eldredge and Kyrazis (2) indicate that there is only an 8-db. to 10-db. maximum spread of sound pressure levels for 13 different types of jet fighter and bomber aircraft. This would indicate that various jet aircraft would be aurally detected at approximately the same ranges under the Tonopah test conditions.

The extent to which the detection of jet aircraft can be aided by the auditory sense is a function of aircraft speed, the amount of terrain masking, and meteorological conditions. The more visibility is limited, the greater role the ear can play in detection of aircraft.

Visual Aids

The results of the studies evaluating the use of binoculars under conditions of far terrain masking indicated that the visual detection ranges of aircraft were not extended when either the 6x30 or 7x50 binoculars were used. These results support those obtained in a previous test reported by Wright (1). The results obtained by Wright and those reported here do not support the results obtained in 1957 by Kurke and McCain (3). Kurke and McCain found that mean detection ranges varied fairly regularly from 14,500 yards to 18,000 yards as optical power increased from 3-power to 7-power. However, the Kurke and McCain study used a tripod-mounted monocular optic that was aimed at a fixed sky point into which the target aircraft flew. In contrast with the Kurke and McCain study, the tests reported here (as well as that conducted by Wright) used hand-held binoculars and required search of the horizon. Under these more tactically realistic conditions of use, the increase in optical power over unaided vision did not result in a reliable increase in detection range.

Although the intended function of binoculars is to increase detection range by magnifying the image size, binoculars also limit the field of view. The terrain masking tests indicate that detection range was reduced by using 6x30 binoculars. Apparently, the advantage of magnification was overcome by the limited visual field of the binoculars. In other words, when the observers were positioned in such a way that the aircraft was visible to the naked eye as soon as it broke mask, magnification provided no advantage. The limited field of the optics reduced the effective search area to the detriment of detection range.

Early Warning

Early warning (EW) involves providing information concerning the present or expected position of an aircraft with reference to both time and location. Wokoun (4) has previously examined the influence on detection ranges of varying the size of the search sector while holding time constant. Wokoun used four search sectors, 45°, 90°, 180°, and 360°, but provided no temporal EW. The Tonopah test situation provided an opportunity to evaluate variation in temporal warning while holding search area constant. The results indicated that when the flight path of the aircraft was known within a few degrees, variation in temporal early warning between one and five minutes was of no consequence.

Observer Offset

The amount the observer was offset from the flight path of the aircraft proved to be of some importance, probably for two reasons. First, as the OP distance increased, the aspect angle of the target increased. The larger the target, the sooner it will be detected within the limits of visibility and masking. Second, the more lateral OPs were at a higher elevation, resulting in a slightly more distant horizon for these OPs. However, the offset distance becomes tactically important in the location of OPs or weapons sites only when the flight paths of target aircraft can be anticipated.

Chapter 3

RANGE ESTIMATION TESTS

The maximum effectiveness of many air defense weapons in part depends upon accurate estimates of the range of targets. However, very few data are available concerning range estimation of aerial targets by a ground observer. For the study reported here, pilot tests of range estimation were designed to provide preliminary information that would be of future use in designing training procedures.

PROCEDURE

During eight of the test days the observers stationed at all four offsets were required, on command of HumRRO Test Control, to estimate the range from their position to the inbound aircraft. Depending upon the observers' offset from the flight line, the true slant ranges varied between 1,000 and 5,000 meters. The actual position of the aircraft along the flight path at the time of the "Range Mark" command was either 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, or 4,000 meters from the crossover point. Using a simple sighting bar and a randomized schedule of ranges, the true flight line distance of the aircraft at the time of the "Range Mark" command was known by Test Control.

Although flight line distances of 1,000, 1,500, 2,000, 2,500, 3,000, 3,500, and 4,000 meters were used by Test Control, it should be noted that the differences between the corresponding minimum and maximum actual slant ranges were not constant for the four OPs. As the offset increased, the difference between maximum and minimum slant ranges decreased. Immediately after the aircraft reached the crossover point, Test Control informed observers of true range from the crossover point (the flight line distance), and the observers, using a conversion table prepared for each offset, converted the announced flight line distance to the corresponding slant range for their position. Although this procedure delayed the feedback to the observer, it was the only method available for training that would not interfere with the other concurrent HumRRO test objectives.

RESULTS

The range estimates obtained during eight days of fighter and bomber flights were averaged over days for each of the four observation posts. Table 6 presents the mean algebraic errors and standard deviations of the range estimates given for each true slant range. At the 200-meter OP the observers consistently tended to underestimate the true slant range. For example, on the average, they estimated an aircraft that was actually 4,000 meters away to be 3,200 meters distant.

Also presented are the average of the mean algebraic error, and the mean absolute error for each OP. Not only did the average error decrease as the observer's offset increased, but there was a definite trend for the variability

Table 6

Mean Error of Estimation of True Slant Range for Each Offset

(Meters)

Item	Offset											
	200-Meter			1,400-Meter			2,600-Meter			3,300-Meter		
	Slant Range	Mean	SD	Slant Range	Mean	SD	Slant Range	Mean	SD	Slant Range	Mean	SD
Flight Line Distance												
1,000	1,000	- 20	283	1,700	+ 100	300	2,800	+ 33	492	3,400	+ 33	206
1,500	1,500	- 371	175	2,100	- 140	133	3,100	- 144	223	3,600	+ 83	195
2,000	2,000	- 167	867	2,400	+ 83	546	3,300	+ 67	340	3,800	+ 117	299
2,500	2,500	- 578	764	2,900	+ 144	741	3,600	+ 222	560	4,100	+ 111	520
3,000	3,000	- 300	616	3,300	+ 467	419	4,000	+ 167	330	4,300	- 25	785
3,500	3,500	- 738	795	3,800	- 575	524	4,400	- 20	613	4,700	+ 100	487
4,000	4,000	- 814	747	4,200	- 333	615	4,800	- 183	694	5,000	- 133	549
Mean Algebraic Error		- 476	727		- 81	621		- 29	535		+ 53	468
Mean Absolute Error		702			463			371			359	
Difference Between Minimum and Maximum Slant Range	3,000			2,500			2,000			1,600		

among estimates (as reflected by the size of the standard deviations) similarly to decrease.

The trend for average absolute error to decrease as offset increased was attributed to the systematic restriction in the minimum-maximum slant ranges as offset increased. This progressively limited the upper and lower limits of the possible range estimates. The ratio of average absolute error to the maximum-minimum difference was essentially constant for all OPs.

For each OP the correlation between true slant range and mean algebraic error of the estimates was computed:

(1) 200-meter OP: +.85
(2) 1,400-meter OP: -.43
(3) 2,600-meter OP: -.25
(4) 3,300-meter OP: -.54

Only the correlation for the 200-meter OP was reliably different from zero ($p < .05$, $df = 5$). Whereas there was a consistent trend for the magnitude of the underestimation at the near OP to increase as slant range increased, this relationship did not prevail at the more lateral OPs. At these OPs the average errors included overestimations as well as underestimations, and there were no pronounced trends for the magnitude of the estimation error to change systematically as a function of true slant range.

DISCUSSION

Average Error

The reduction in average error (algebraic) from -476 meters for the 200-meter offset to +53 meters for the 3,300-meter offset is believed to be a result of unique characteristics of the testing situation. The aircraft flight path was constant and known to the observers, and the observers obtained feedback on the actual slant range of the aircraft after each pass.

In addition, for the OPs beyond 200 meters it was possible for many of the observers to partition the 1,000-meter to 4,000-meter flight line distance into segments by using background terrain features, and then to use these references to estimate the range to the aircraft. As a result, in this test situation the estimation of the aircraft's distance relative to the OP could be reduced to an estimate of its position relative to the terrain feature. It is believed that the observers at the 200-meter OP could not use this method as successfully since the aircraft was almost head-on and its position relative to terrain features could not be accurately judged.

These test results indicate that when the aircraft's flight path was overhead or diving, substantial underestimates of the physical distance occurred. This would tend to cause gunners to fire at aircraft beyond the effective range of their weapon.

Error Dispersion Index

In an effort to combine the two sources of estimation errors—error due to individual differences and error due to a constant bias associated with the OPs—into one index, the mean and standard deviation of the algebraic error were used to compute an "Error Dispersion Index" (ξ), which is equal to the square root of the second moment about zero error: $\sqrt{{}_0\mu_2^{2}} = \sqrt{M^2 + \sigma^2}$. This index provides a measure of the total dispersion of the estimation errors about the true slant range. The index reflects constant biases and variation due to individual differences. Table 7 presents the Error Dispersion Index for each OP associated with each slant range.

Table 7

Error Dispersion Index[a] for Each Slant Range

(Meters)

Flight Line Distance	Offset: 200-Meter Slant Range	Index	1,400-Meter Slant Range	Index	2,600-Meter Slant Range	Index	3,300-Meter Slant Range	Index
1,000	1,000	283	1,700	316	2,800	493	3,400	208
1,500	1,500	410	2,100	193	3,100	265	3,600	212
2,000	2,000	883	2,400	552	3,300	686	3,800	321
2,500	2,500	957	2,900	754	3,600	602	4,100	531
3,000	3,000	685	3,300	627	4,000	382	4,300	785
3.500	3,500	1,084	3,800	778	4,400	614	4,700	497
4,000	4,000	1,105	4,200	699	4,800	717	5,000	556
Mean		859		626		535		471

[a] $\sqrt{{}_0\mu_2^{2}}$

The correlations between the Error Dispersion Indices and the true slant ranges were computed for each OP:

(1) 200-meter OP: $r = +.86$
(2) 1,400-meter OP: $\bar{r} = +.81$
(3) 2,600-meter OP: $\underline{r} = +.47$
(4) 3,300-meter OP: $\underline{r} = +.71$

Only the correlation coefficients for the 200-meter and 1,400-meter OPs were significantly different from zero ($p < .05$, $df = 5$). As shown in Table 7, there was a rather regular trend for the magnitude of the index to increase as slant range increased.

Average Error vs. Dispersion Index

In comparing the average algebraic error for each OP (Table 6) with the average Error Dispersion Index (Table 7), it can be seen that, except for the 200-meter OP, the OP bias contributed very little to the overall error of estimation. The percentages of the index that were due to constant bias at each OP are:

(1) 200-meter OP: 30.0%
(2) 1,400-meter OP: 1.7%
(3) 2,600-meter OP: 0.3%
(4) 3,300-meter OP: 1.3%

Although the location of an observer relative to the flight path of an aircraft contributes some error to range estimates, the largest single error source is that due to individual differences. The observers used in these tests were untrained. It is believed that with an appropriate training procedure the individual differences in range estimation would be reduced greatly.

It is evident that additional training studies are needed to identify the type and amount of training required to reduce estimation errors.

Chapter 4

STRUCTURE IDENTIFICATION TESTS

The probability that an aircraft will be correctly identified varies inversely with the aircraft-observer distance. As the aircraft approaches the observer, he is able to distinguish and differentiate a progression of structures and structure interrelationships. Since there may be typical distances at which certain structures are detected, such information might serve as a basis for range estimation in addition to aiding aircraft identification. Tests were conducted to determine the distances at which various aircraft components are detected.

PROCEDURE

Observers were stationed at the 200-meter and 1,400-meter observation posts. For any one aircraft pass, one-half of the observers served as observers and the remainder functioned as umpires. Two observers used field glasses and two used unaided vision on each pass. Observers were rotated between the two OPs every four passes, and they alternated the viewing systems with each pass. A sample of the detailed test schedule is shown in Table 8 for four men at one OP.

Four tests were conducted—one each for the F-4C, A-6, B-52, and B-58 aircraft. Each test involved 16 aircraft sorties, and since the men alternated as observer and umpire, each observer participated in eight sorties per test.

Table 8

Sample Schedule of Structure Recognition Test

Aircraft Pass	Personnel	Personnel Function	Offset (meters)	Visual Aid
1	A	Umpire	200	–
	B	Observer	200	None
	C	Umpire	200	–
	D	Observer	200	6 × 30
2	A	Observer	200	None
	B	Umpire	200	–
	C	Observer	200	6 × 30
	D	Umpire	200	–
3	A	Umpire	200	–
	B	Observer	200	6 × 30
	C	Umpire	200	–
	D	Observer	200	None
4	A	Observer	200	6 × 30
	B	Umpire	200	–
	C	Observer	200	None
	D	Umpire	200	–
5-8	Rotate to 1,400-meter OP and repeat schedule of 1-4.			

During each pass the observer activated an event recorder pen at the time of initial detection of the aircraft. Subsequently, whenever he detected a structural component--for example, the wings—he told his umpire and simultaneously activated his event recorder pen. As the aircraft continued its approach, this procedure continued until the aircraft reached crossover. The umpire's report of the sequence of detecting structures subsequently was collated with the distance information derived from the event recorder tapes.

During these tests the observers were limited to reporting detection of seven or eight major structures because umpires were not able to accurately record the correct sequence when a greater number of structures were reported.

RESULTS

Detection Distance

The mean ranges to the aircraft at the time sighting of major structural components was reported are presented in Table 9 for unaided observations, and in Table 10 for observations with 6x30 binoculars.

Table 9

Mean Detection Ranges for Structural Components With Unaided Vision

OP and Component	Aircraft Observed											
	F-4C			A-6			B-52			B-58		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
200-Meter Offset												
Initial detection	15	6,250	1,282	16	6,700	2,336	15	8,850	2,697	15	10,200	1,344
Fuselage	8	4,100	1,048	13	3,900	2,045	14	4,900	3,471	12	4,450	2,457
Wing	15	3,450	713	16	2,950	770	15	7,250	2,968	14	6,150	1,668
Vertical stabilizer	15	2,100	748	16	2,100	970	15	4,000	1,931	14	2,800	1,456
Wing extension	7	1,750	1,169	12	1,950	645	NR	NR	NR	NR	NR	NR
Canopy	13	1,350	668	10	1,050	490	11	1,200	324	13	1,600	455
Nose	11	1,350	1,072	15	1,200	606	13	2,400	1,088	14	1,000	511
Horizontal stabilizer	11	1,150	785	10	550	436	9	800	948	NR	NR	NR
Air intake	12	1,000	738	5	550	521	NR	NR	NR	NR	NR	NR
Engine pod	NR	NR	NR	NR	NR	NR	15	5,150	2,382	15	3,550	1,006
1,400-Meter Offset												
Initial detection	16	5,100	610	16	5,050	760	16	10,900	3,400	13	12,500	2,060
Fuselage	7	3,650	1,094	15	3,800	844	16	8,550	2,934	14	6,000	3,800
Wing	7	3,450	798	7	3,050	1,539	16	8,850	4,394	13	7,500	1,600
Vertical stabilizer	14	3,950	480	16	4,050	419	16	7,200	2,326	14	6,600	942
Wing extension	7	3,000	365	5	1,850	223	NR	NR	NR	NR	NR	NR
Canopy	13	2,300	352	13	2,150	655	12	2,350	907	14	2,750	922
Nose	14	2,250	808	16	2,600	543	16	3,800	1,287	14	2,650	460
Horizontal stabilizer	12	2,000	297	11	1,850	293	10	1,800	690	NR	NR	NR
Air intake	5	1,850	397	NR	NR	NR	NR	NR	NR	NR	NR	NR
Engine pod	NR	NR	NR	NR	NR	NR	16	7,300	2,160	13	4,300	1,189

*NR = Not Reported

Table 10

Mean Detection Ranges for Structural Components With Binoculars

OP and Component	Aircraft Observed											
	F-4C			A-6			B-52			B-58		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
200-Meter Offset												
Initial detection	15	6,350	1,093	13	6,300	1,376	16	9,150	2,932	14	9,850	1,190
Fuselage	10	4,050	2,226	10	5,000	2,152	14	4,350	3,371	14	5,850	3,034
Wing	14	5,350	845	12	5,500	704	15	8,250	2,736	14	8,750	1,502
Vertical stabilizer	14	3,750	1,269	13	4,750	1,810	15	7,300	2,390	14	5,150	1,444
Wing extension	6	4,850	620	11	4,650	965	NR	NR	NR	NR	NR	NR
Canopy	12	2,650	861	11	3,250	1,905	11	3,350	1,496	14	2,900	1,375
Nose	12	2,150	1,421	13	2,200	1,162	15	4,950	1,981	14	2,350	1,099
Horizontal stabilizer	13	1,700	734	8	950	745	12	4,300	1,426	NR	NR	NR
Air intake	14	3,650	777	12	2,800	622	NR	NR	NR	NR	NR	NR
Engine pod	NR	NR	NR	NR	NR	NR	15	7,350	2,413	14	7,850	1,964
1,400-Meter Offset												
Initial detection	16	4,700	586	16	4,800	587	16	11,050	3,491	13	12,500	1,893
Fuselage	10	3,150	1,076	14	3,450	849	15	8,650	2,980	13	8,650	3,715
Wing	12	3,650	938	15	3,700	592	14	9,950	3,164	14	11,050	2,362
Vertical stabilizer	14	4,000	713	16	4,100	581	15	9,800	3,171	14	9,050	1,586
Wing extension	6	3,600	810	12	2,700	822	NR	NR	NR	NR	NR	NR
Canopy	15	2,750	656	15	2,550	625	11	4,600	1,463	14	6,050	1,226
Nose	15	3,100	651	15	2,750	613	15	6,200	2,531	14	4,850	1,409
Horizontal stabilizer	15	2,500	973	15	2,150	514	9	3,600	1,735	NR	NR	NR
Air intake	7	2,350	660	6	2,350	615	NR	NR	NR	NR	NR	NR
Engine pod	NR	NR	NR	NR	NR	NR	15	9,950	3,254	14	9,450	2,009

The structure detection distances are different for the fighters and the bombers because the bomber flights were subject to near terrain masking and the fighters were not. However, within each aircraft class (i.e., fighters or bombers) there was a definite rank ordering of the detections of aircraft structural components.

The sequence of appearance of structures for the observations made with both unaided vision and the 6x30 binoculars at the 200-meter OP are presented in Table 11. For each combination of type of aircraft (e.g., fighters) and viewing system, the orders of appearance of structures were quite comparable for different aircraft. In contrast, there were consistent differences between the fighters and bombers and also between the unaided and aided observations. In most cases, the differences between types of aircraft occurred in the initial two to three structures detected. For bombers, the wings were always the first structures reported. For fighters, the wings were reported first when the men used field glasses, but the fuselage was the initial structure when unaided vision was used.

Table 11

Sequence of Detection of Structural Components

OP and Component	Unaided Vision				Binoculars			
	Fighters		Bombers		Fighters		Bombers	
	F-4C	A-6	B-52	B-58	F-4C	A-6	B-52	B-58
200-Meter Offset								
Fuselage	1	1	3	2	3	2	5	3
Wing	2	2	1	1	1	1	1	1
Vertical stabilizer	3	3	4	4	4	3	3	4
Wing extension	4	4	-	-	2	4	-	-
Canopy	5	5	6	5	6	5	7	5
Nose	6	6	5	6	7	7	4	6
Horizontal stabilizer	7	7	7	-	7	7	6	-
Air intake	8	8	-	-	5	6	-	-
Engine pod	-	-	2	3	-	-	2	2
1,400-Meter Offset								
Fuselage	2	2	2	3	1	3	4	4
Wing	3	3	1	1	2	2	1	1
Vertical stabilizer	1	1	4	2	1	1	3	3
Wing extension	4	6	-	-	3	5	-	-
Canopy	5	5	6	5	6	6	6	5
Nose	6	4	5	6	5	4	5	6
Horizontal stabilizer	7	7	7	-	7	8	7	-
Air intake	8	-	-	-	8	7	-	-
Engine pod	-	-	3	4	-	-	2	2

Table 11 presents similar data for the observations made at the 1,400-meter OP. Again, there was considerable consistency within an aircraft class for each viewing system. Although use of binoculars did not alter the first structure reported, the glasses did affect the order of detecting subsequent structures. By comparing the two sets of observations it can be seen that the orders of appearance of structural components apparently were affected by the observers' offset from the flight path. This is understandable since certain structures (for example, the vertical stabilizer) were masked by other structures when the aircraft is viewed head-on, and the visible areas of some structures change from head-on to a side view.

Response Latency

Response latency—time delay between detection of aircraft and identification of first structural component—was also analyzed. When glasses were used to observe fighters, an average recognition lag of approximately 2.7 seconds occurred for both OPs. When observations were made by unaided vision, a lag of 3.9 seconds occurred at the 1,400-meter OP and 8.9 seconds at the 200-meter OP. The complete data are presented in Table 12.

The recognition delays when glasses were used tended to be approximately 50% shorter than for unaided observation.

The delays for bombers were larger than for fighters, probably as a result of the greater detection ranges for bombers, which (a) were not subject to masking by close terrain and (b) presented a larger total area than fighters.

Table 12

Time Delay Between Detection and Identification of First Structural Component

(Seconds)

Aircraft	Time Delay			
	200-Meter Offset		1,400-Meter Offset	
	Unaided Vision	6 x 30 Binoculars	Unaided Vision	6 x 30 Binoculars
Fighters				
F-4C	7.6	2.8	4.3	2.6
A-6	10.1	2.6	3.4	2.7
Average	8.9	2.7	3.9	2.7
Bombers				
B-58	7.6	4.7	5.1	3.3
B-52	14.8	4.9	17.4	7.2
Average	11.2	4.8	11.2	5.2

DISCUSSION

Structure Identification Range

The mean structure identification ranges (in Tables 9 and 10) show that, with one significant exception, the structure identifications occurred earlier when the observers used field glasses. On the average, the bombers' structures were detected 1,600 meters sooner with glasses than without ($p < .01$). Similar results were obtained for the fighter aircraft when viewed from 200 meters; the structures were seen, on the average, 1,650 meters farther out when glasses were used ($p < .01$).

The one exception involved the observations made of fighter aircraft at the 1,400-meter OP. Since these aircraft flew from the north, they were masked by terrain when viewed from the 1,400-meter OP. The results for the unaided vs. aided observations at the 1,400-meter OP are interesting in several respects. First, as discussed in the section dealing with terrain masking, the unaided gross detections occurred, on the average, before the detections when glasses were used. In the case of the F-4C, the unaided detections occurred 400 meters earlier, whereas the average detection of the A-6 was 250 meters earlier for the unaided condition. The interference with early detection probably is due to the relatively small field of view provided by medium-power field glasses, which require continuous scanning of the horizon. These results suggest that the currently issued glasses should not be used for detection where close terrain mask prevails (5,000-6,000 meters).

A second interesting result for the 1,400-meter OP concerned the essential equivalence of the distances at which the first three successive structures were identified by both aided and unaided observation. For example, the first structure was identified on the F-4C and the A-6 at 4,000 meters and 4,100 meters respectively using glasses, and at 3,950 meters and 4,050 meters without glasses. The second structure of the two aircraft was identified at 3,650 and 3,800 meters with glasses and at 3,600 and 3,700 meters without glasses. A similar consistency between viewing systems occurred for the third structure. In contrast with the aided vs. unaided comparisons for the other OP, at the 1,400-meter OP field glasses did not result in earlier identification of the initial aircraft structures when the aircraft emerged from a near terrain mask.

Delay Between Detection and Structure Recognition

Even though the aircraft was sufficiently near for structures to be visible at the time of gross aircraft detection, the structures did not begin to be reported until a few seconds had elapsed. These results suggested the existence of a systematic response delay or "recognition lag." The observers required time to reprogram their intellectual activities from (a) the terrain scanning and searching needed for gross detections to (b) the detailed scanning, sorting, and classifying required for structure recognitions.

The differences in delay time between the OPs for unaided viewing are attributed to the greater distance at which gross detections occurred at the OP closer to the flight path. Comparable similarities and differences were found for the observations of bombers. However, the delays between detection and initial structure identification for bombers were consistently longer than for the fighters. The latter difference may have been due to sun angle effects, since the bombers flew from the south; more probably it was due to the greater total area presented by bombers, which increased the detection ranges for these aircraft.

These results do suggest that a characteristic delay of two to four seconds occurs between the initial detection and recognition activities of observers. The delay was less when glasses were used, but this advantage was negated by the decreased range of initial aircraft detection when glasses were used and the flights were masked by terrain.

This problem deserves additional study since the present data suggest that using field glasses successively for detection and recognition is less efficient than unaided observations when there is a close terrain mask.

The variability of the identification ranges (i.e., the magnitude of the standard deviation) was relatively small for many structural components. This result indicates that observers should be able to use structure detections as a reliable basis for estimating aircraft distance. Additional studies of this skill are needed to determine whether the differences between the individual's detection ranges for specific structures can be reduced through training.

Chapter 5

AUDITORY TRACKING TEST

BACKGROUND

The objective of the research being conducted under HumRRO Work Unit SKYFIRE is to enhance the capabilities of forward area air defense (FAAD) weapons. Since these weapons are visually sighted, they are currently considered to have limited effectiveness under conditions of reduced visibility. However, recent developments in the field of infrared (IR) imagery suggest that IR sensors might be used as visual aids to permit FAAD weapons to track aircraft under other than fair weather conditions. Since current IR imagery devices have a rather restricted field of view, however, their use for initially acquiring a rapidly moving aircraft is limited.

One possible method of overcoming this obstacle to the use of IR imagery is to have gunners use their auditory sense for initially localizing the aircraft. As was described in Chapter 2, under conditions of near terrain masking it was found that auditory detection and visual detection occurred at comparable aircraft-to-observer distances. These results suggest that the auditory sense could be used for initial detection of aircraft under poor visibility conditions. A question remains concerning the ability of gunners to localize and track jet aircraft using only auditory cues.

In a recent study by Bauer (6), observers were required to localize a low-speed helicopter flying offset (tangential) and overhead flight paths. Bauer found that, when averaged over all flight paths and aircraft distances, the mean absolute error in localizing the true location of the sound source varied between 9° and 18°. Since no field studies of auditory tracking of higher-speed aircraft have been conducted, it appeared important to perform a preliminary test to evaluate the generality of Bauer's results.

PROCEDURE

The tests were conducted with untrained observers who used only the auditory sense to track the position of an A-6 aircraft. Eight observers each tracked nine flights from the 2,000-meter OP, using specially constructed azimuth pointing boards. The observers were positioned 2,000 meters from the flight path at the HumRRO Test Control Site. The pointing errors of apparent vs. actual position were determined for slant ranges of (a) 4,500 and 2,800 meters approaching, (b) 2,000 meters crossover, and (c) 2,800 and 4,500 meters departing.

The boards, each having a graduated scale and a movable pointer, were constructed with a microswitch at the end of the pointer. This switch was triggered during movement of the pointer at azimuths corresponding to the five points along the flight path. The apparent location of the aircraft was marked on a separate channel of the event recorder for each observer. One additional channel was used to indicate actual positions of the aircraft during its run along the flight path. These positions were determined by a visual sighting device and were marked by Test Control personnel using a hand-actuated microswitch.

Observers were instructed to stand at their respective azimuth boards with eyes closed and with their preferred hand and arm resting on the pointer. As an observer became aware of the plane's approach, he positioned the arm at the point of detection and then tracked the plane's sound (its apparent position) during the remaining audible portion of the flight. The observers had no prior training in this operation and were not informed of their errors during the tests.

For the day on which the study was done, the temperature ranged from 54° at 0700 to 75° at 1100. Relative humidity during this period decreased from 68% to 25%. Wind direction was constant from the north, the direction from which the flights originated. Wind speed averaged 10 miles per hour for six observations, but during two flights the wind was slight to calm. In the desert terrain auditory masking occurred chiefly from wind noises. These originated both when the wind cut across the observer's external ears and when it blew through the sparse sage brush ground cover. A few random aircraft flew at high altitudes across the test site on several trials and provided intermittent masking of the engine sounds of the test aircraft.

MEASURING TRACKING ERROR

At any instant in time, a moving, sound-emitting target has both a true apparent position when sensed via auditory cues and a true physical position which leads the apparent position. The amount by which the target leads its apparent position is a function of the speed of sound, the velocity of the aircraft, and the distance of sound source from the observer.

The total error in auditorily localizing the physical position of a moving sound source may be partitioned into two categories:

(1) The error due to acoustic lag, which is determined by the speed of sound, aircraft velocity, and observer's distance from the source.

(2) The error due to human fallibility in sensing the true position of the apparent source and indicating the location of the source.

Figure 10 schematizes the two categories of error. The angular error, •, due to acoustic lag is equal to the angle AOT, where A is the location of the source at a given instant in time, O is the position of the observer, and T is the new position of the sound source at the time that the original sound wave reached the observer. The acoustic lag angle, •, will vary directly with the velocity of the aircraft, the distance AO, and any factors which influence the speed of sound.

Geometry of Auditory Tracking

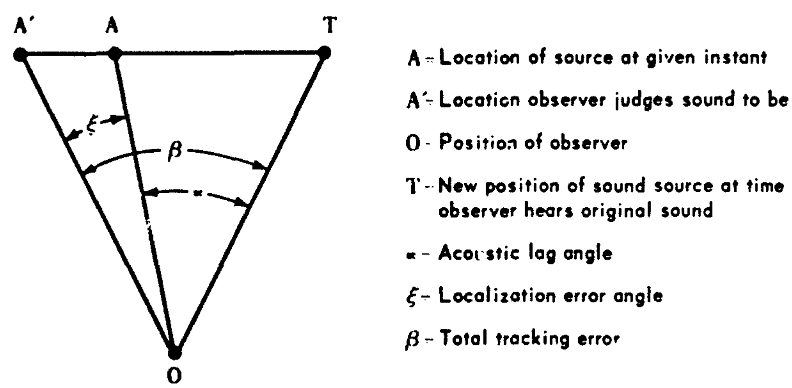


Figure 10

When the sound emitted at A reaches O, the observer makes a judgment concerning the location of the source. Although the aircraft actually is physically now located at point T, the observer will judge the sound source to be located at A′. The observer, therefore, will introduce localization errors that can lag, lead, or coincide with point A by an angle ξ. In order to obtain an estimate of man's capability of auditorily tracking a moving source, it is necessary to eliminate from the total tracking error, the error component due to acoustic lag.

RESULTS

The localization errors for five aircraft-to-observer slant ranges are presented in Table 13. The table contains (a) the average total algebraic angular error, (b) the standard deviation of the individual's errors about the mean, (c) the acoustic lag angle between the true and apparent physical location of the aircraft, (d) the mean human tracking error, and (e) the Dispersion Index of the tracking errors. As shown in this table, all mean errors lagged the physical location of the target, except human error, which led the apparent position of the sound.

Table 13

Mean Angular Tracking Errors[a]

(Degrees)

Slant Range to Aircraft	Total Error		Acoustic Lag Angle	Mean Human Tracking Error	Dispersion Index[b]
	Mean	SD			
Incoming					
4,500 M	-31.6	13.9	-35.2	+3.6	-34.5
2,800 M	-35.3	11.3	-39.9	+4.6	-37.1
2,000 M	-28.0	7.6	-32.5	+4.5	-29.0
Outbound					
2,800 M	-11.6	5.7	-17.3	+5.7	-12.9
4,500 M	- 4.1	4.2	-10.3	+6.2	- 5.9

[a]The direction of error is indicated by + or − .
[b]$\sqrt{M_T^2 + SD^2}$

As indicated by the change in the magnitude of the Dispersion Index, the total dispersion of tracking errors decreased fairly regularly as the target's position changed from incoming to outbound.

In addition, inspection of the average human errors indicates that the observers tended to lead the apparent position of the sound and became more consistent with one another as the flight progressed from inbound to outbound. The relationship among the several measures and sources of error are also shown in Figure 11. This figure strikingly portrays the relative constancy of the average human error and the marked dependence of the total tracking error on the acoustic lag angle.

DISCUSSION

The total tracking errors obtained in this test are similar to those reported by Bauer. The results indicated that the major source of error in auditory tracking was due to acoustic lag. The observers' average localization errors were relatively small and led rather than lagged the apparent source.

Although the human error is small, the total tracking errors are quite large. Additional studies are needed to determine if training procedures can be devised that will reduce the total tracking error.

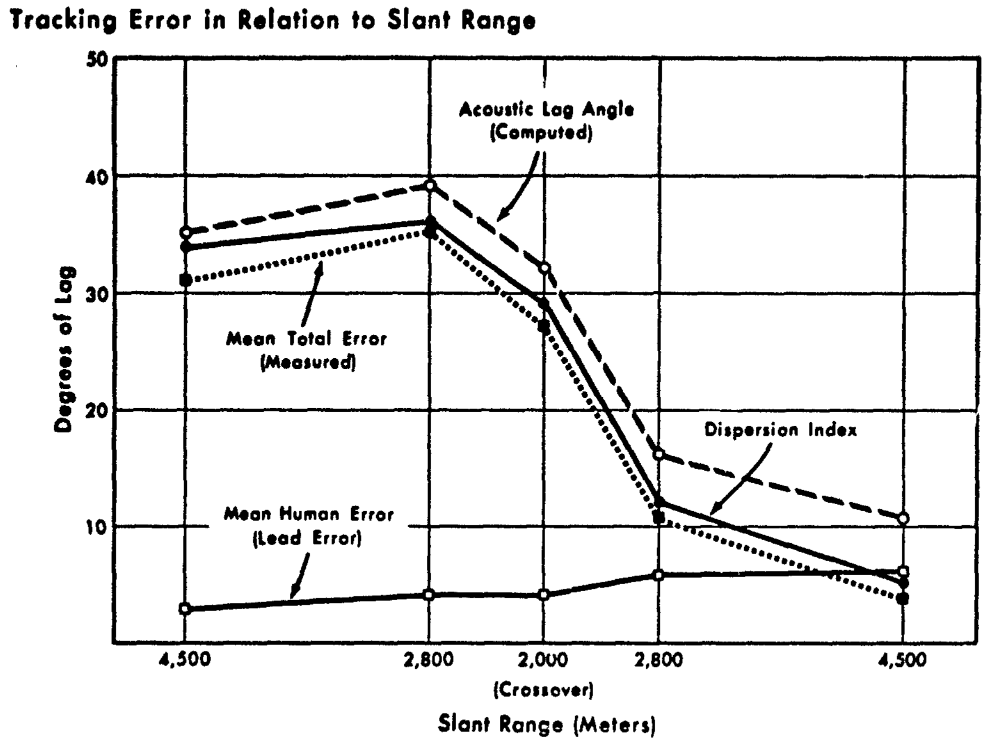


Figure 11

LITERATURE CITED
AND
APPENDIX

LITERATURE CITED

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Appendix

PLAN OF THE SITE AND TEST EQUIPMENT

This Appendix is added for historical reasons, to provide information to those who may become involved in similar field testing, since field testing becomes rather complex even for a small study.

1. Location of Survey Points

a. Initial point. A drum on the Center Line served as initial point.

b. Offsets. Using an aiming circle and surveyor's tape, observation posts (OPs) were located 200, 1,400, 2,600, and 3,300 meters from the flight line, along a line perpendicular to and west of the flight line. (Survey equipment yielded accuracies of 1/500, so that all stations were located to an accuracy of ±8 meters.) The OPs were marked by seven-foot, flag-topped stakes.

c. Test Control. Test Control was located 2,000 meters from the flight line, on the perpendicular to the flight line. Test Control was marked by a seven-foot stake.

d. Aiming stakes. Four seven-foot, flag-topped aiming stakes were placed on a line that paralleled the line of flight and passed through the 200-meter OP west of the flight line. Aiming stakes were placed so that, when viewed from Test Control, they defined points 4,000 and 2,000 meters south of the crossover range at the flight line and 4,000 and 2,000 meters north of the crossover range at the flight line.

e. Geographic location of the test site. Test Control was located by map inspection and by resection, using an aiming circle and known locations in the area.

f. Time and personnel. Surveying and marking the nine points indicated above required the services of four men for eight hours, and a vehicle.

2. Site Instrumentation

a. Equipment netted with wire

(1) One field phone was located at each of the OPs and at Test Control.

(2) A 20-channel event recorder was located at Test Control and its power source, a 1.5-kw. gasoline generator, was located 250 feet north of the recorder. The generator was placed in a sandbag enclosure to reduce noise.

(3) A tape recorder, inverter-powered from a 12-volt battery, was, on certain test days, located at the 200-meter or 1,400-meter OP.

b. Wiring

(1) Wiring diagram. The four test sites were connected to Test Control by the system shown in Figure A-1. Line 1 was a communications line to which one field phone was connected at each of the five positions. Line 2 was a spare wire used for two additional clipboards at position four. Line 3 was a return wire for the pushbutton system for recording range information. Lines 4-9 were for hot lines for pushbuttons. Lines 5 and 7 were used for extra clipboards located at Offsets 1 and 2 when the eight observers were distributed over these two offsets. All wires were double-strand.

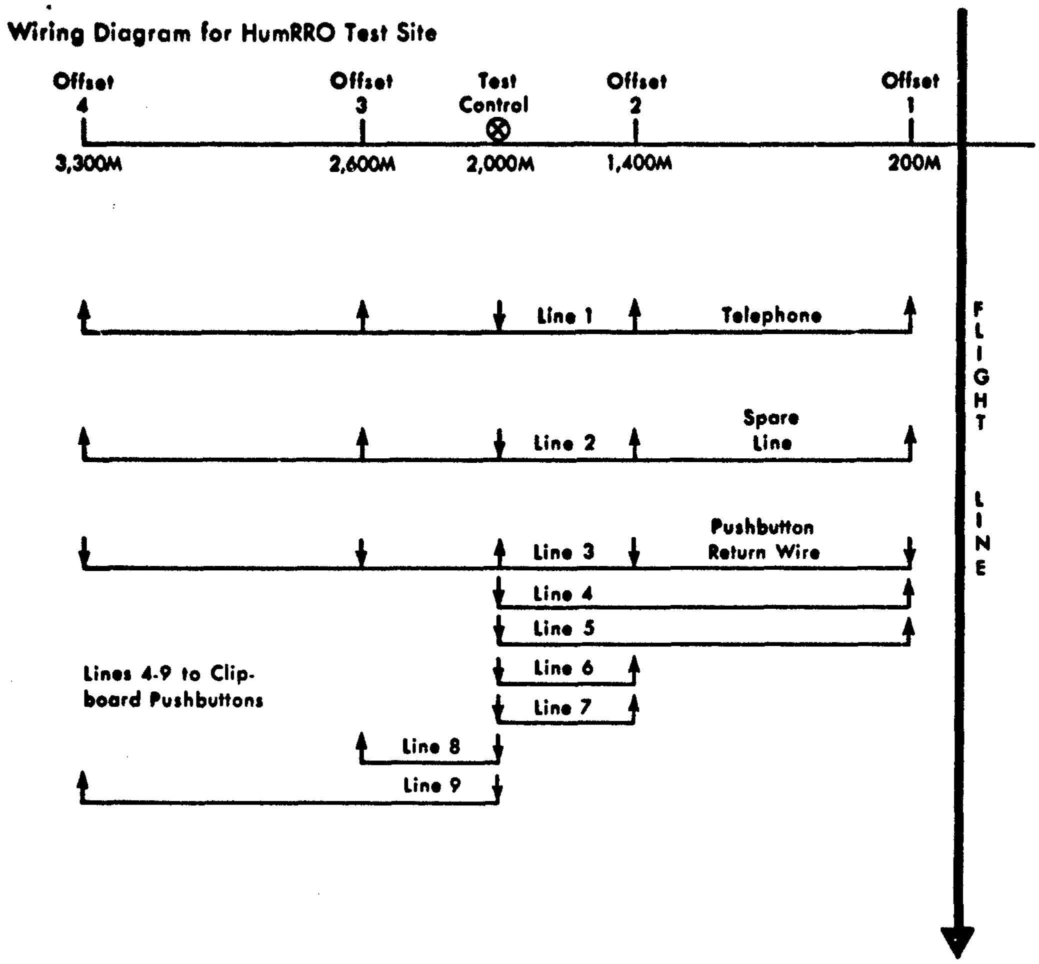

Figure A-1

(2) Hook-up to event recorder. When two observers were at each offset, Line 4 wires were hooked up to Pens 1-2, Line 6 wires to Pens 5-6, Line 8 wires to Pens 9-10, and Line 9 wires to Pens 11-12. When four observers were at Offset 1 and four at Offset 2, Line 4 and Line 6 wires were hooked up as above. Line 5 and Line 7 wires were connected to Pens 3-4 and 7-8. Pen 20 was used by Test Control to record the time when the aircraft was at a pre-crossover range of 2,000 meters from crossover range, when it was at cross-over, and when it was at a post-crossover range of 2,000 meters.

(3) Wire-laying. Approximately 11.5 miles of double-strand field wire was needed. The wire was buried to a depth of one to three inches. It was spooled from numbered reels and the ends were tagged at each position. Following checkout, the wire was buried in a shallow trench. Wire-laying required the services of four men for eight hours. Wire-burying required four men for about six hours. Two days were required to set up all equipment.

c. Other Equipment

(1) A single side-band radio for communication with Joint Task Force Two Control was positioned at HumRRO Test Control. Its antenna was pole-mounted nearby.

(2) A wind speed measuring device was located at Test Control for use in measuring ground wind speed from time to time.

(3) A wetbulb-drybulb thermometer was located at Test Control for use in measuring temperature.

(4) Testing equipment and tools were located at Test Control.

(5) An azimuth-measuring device, graduated in increments of 500 meters when sited at Test Control, was located at Test Control.

(6) A visual elevation-measuring device was located at Test Control. This device was graduated in increments of 25 feet at the flight line when it was sited at Test Control.

3. Equipment. The equipment required for the tests is presented below:

Quantity	Item
2	20-channel event recorder
2	1.5-kw. skid-mounted gasoline generator set, 120-V single phase AC, G 1536A-2A016 (Military)
1	1/4-watt, battery-operated Transponder (supplied by JTF-2)
1	Stereophonic magnetic tape recorder
2	Condenser microphone with power supplies
1	275-watt inverter
1	12-V, heavy-duty storage battery
1	12-V, 3-amp. battery charger
1	Single side-band tranceiver and antenna, 4.603 mc.
15 mi.	WD-1 field wire (military)
1	M-1 aiming circle (military)
10	Field phone set, TA-312/PT (military)
400 ft.	Recording tape
2	Microphone stand
6	6x30 binoculars
6	7x50 binoculars
12	Clipboard fitted with pushbuttons
Asstd	Wooden stakes and poles, flags
1	100-meter measuring tape
4	Field table and camp stool
2	Gas can
1	250-ft. power cable
2 boxes	Recorder chart paper
1	Altitude measuring device
1	Wet-Dry bulb thermometer

Quantity	Item
1	Wind speed measuring device
4	Stopwatch
2	Typewriter
1	Calculator
1	Multimeter
Asstd	Tools and spare parts
1	Four-wheel-drive pick-up with camper
2	Station wagon

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13. ABSTRACT

Detection tests with low-flying jet aircraft were conducted to determine the effect of (a) varying the location of observers from the flight path, (b) using optical aids vs. unaided observation, and (c) varying the amount of temporal early warning. Also tested were man's ability to (a) visually estimate the distance to high-speed jets, (b) track aircraft by ear, and (c) determine the distances at which various aircraft structural features were recognized. When distant terrain masking existed, unaided and optically aided detections occurred at approximately the same time. However, when near terrain masking existed, unaided detections occurred sooner. Using binoculars resulted in earlier recognition of structural features. A change from one minute to five minutes of temporal early warning did not affect detection range. As offset increased from 200 meters to 3,300 meters, detection range increased. The range estimation tests were inconclusive. The results of the auditory tracking tests suggest that it may be possible to extend the capabilities of some fair weather air defense systems to poor visibility conditions. The order in which structural features were recognized was different between fighters and bombers, but there were consistencies within each class of aircraft.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Aircraft Detection						
Aircraft Recognition						
Visual Aids						
Visual Skills						
Range Estimation						
Auditory Detection						
Auditory Tracking						
Auditory Localization						

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